APPLICATION OF THE PERMEAMETER DEVICE FOR DETERMINING RELATIVE PERCENTAGES OF DOWN AND FEATHERS IN DOWN AND FEATHER MIXTURES

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APPLICATION OF THE PERMEAMETER DEVICE FOR
DETERMINING RELATIVE PERCENTAGES OF DOWN
AND FEATHERS IN DOWN AND FEATHER MIXTURES

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APPLICATION OF THE PERMEAMETER DEVICE FOR DETERMINING RELATIVE PERCENTAGES OF DOWN AND FEATHERS IN DOWN AND FEATHER MIXTURES

CHAPTER I

PURPOSE OF STUDY

The problem of determining percentages of down and feathers in down and feather samples has a twofold purpose: (1) to facilitate enforcement of legal and contractual requirements and (2) to reduce the time needed to make a sample analysis.

The present method of sampling and analysis is usually prescribed by law. For example the laws of the state of New York[1], which are generally accepted by other states, require that a sample be taken by an inspector from at least three different parts of a feather and down article. These are then mixed completely, and a random representative sample taken out of the mixture and divided into two parts one retained by the manufacturer and the other sent to the bedding division laboratory for analysis. The sample is again mixed, at the

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[1] Law and Rules Applicable to the Manufacture and Sale of Articles of Bedding, Articles of Upholstered Household Furniture and Materials Used Therein. Department of Labor, State of New York. Ninth Edition 1945.

laboratory, and one quarter taken for the actual analysis. This sample is separated into its various components, down and feathers. The law further requires at least three hours of manual separating of down from feathers to obtain an analysis. All products produced containing down and feathers are required to be tagged with the type and percentages of the various materials contained and must conform to the test prescribed.

The problem here investigated concerns the use of the permeameter device as a method of analysis of percentages of down and feathers in a given sample. This method has worked well in fiber-fineness studies and the particular study here discussed offers a simpler and quicker method of analysis.

CHAPTER II

REVIEW OF PREVIOUS WORK

The permeameter device as a method of determining the surface area and thus fineness of fibers has been discussed by Hertel and coworkers, [2,3,4,5] also by Dalla Valle and others of the Georgia Tech Engineering Experiment Station.[6]

Hertel and his coworkers realized that the random packing of the bed has made the obtainment of a uniform porosity very uncertain. An alignment of the fibers was used to remove this drawback. However the job of alignment is tedious and does not completely remove the possibility of nonuniformity of the void spaces essential to

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[2] J. L. Fowler and K. L. Hertel, "Flow of a Gas Through Porous Media," Journal of Applied Physics, 11:496-502, July, 1940.

[3] R. R. Sullivan and K. L. Hertel, "Flow of Air Through Porous Media," Ibid., 11:761-5, December, 1940.

[4] R. R. Sullivan, "Further Study of Flow of Air Through Porous Media," Ibid., 12:503-8, June, 1941.

[5] R. R. Sullivan and K. L. Hertel, "Surface per Gram of Cotton Fibers as a Measure of Fiber Fineness," Textile Research, 11:30-8, November, 1940.

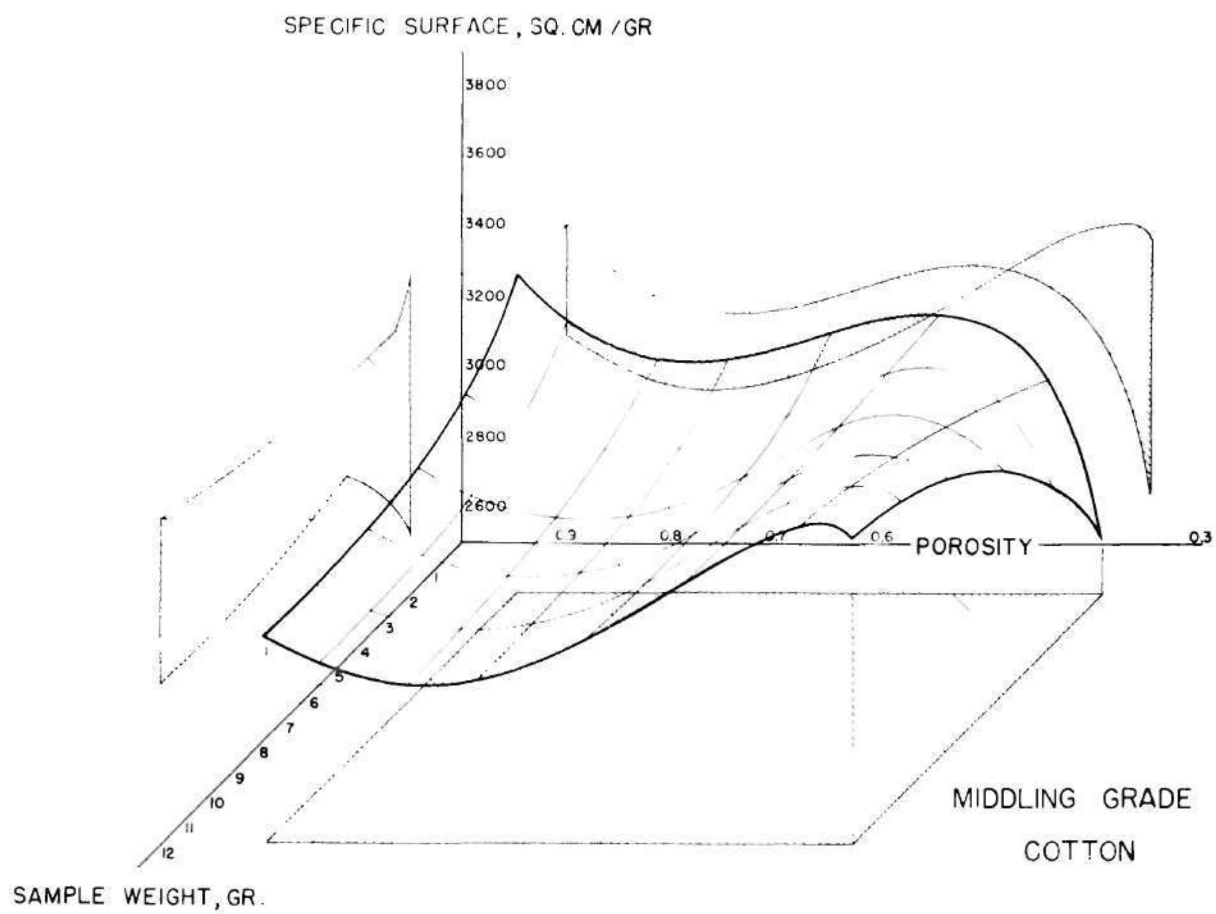
[6] J. M. Dalla Valle, Clyde Orr, Jr., and R. R. Cornwall, "Limitations of the Arealometer Method for the Measurement of Fiber Diameters," Ibid., to be published in 1950.

uniform porosity.

J. M. Dalla Valle, Clyde Orr, Jr., and R. R. Cornwall used a fiber of known surface area and made an investigation of porosity and weight of a sample as they effect the surface area. The results of this investigation are shown in Figure 1. It is clear from this figure that there is a definite effect on the surface area obtained by the variation of the weight of the sample and the porosity. The effect of the porosity on the calculated value of surface area is very marked. For any given sample there is a fair degree of reproducibility provided the values of each of the variables can be kept reasonably constant. With this precaution the results obtained are fairly accurate.

The conclusion drawn from limited data presented by Dalla Valle and coworkers indicates that reproducibility of material with a low surface area are more constant than those with high surface area values. From the general acceptance of the permeameter device in the Textile Industry for fiber fineness determinations and the data presented on fibers it seems to indicate that a rapid method of filling the permeameter could be used on other types of fibrous material such as down and feathers.

FIGURE 1



VARIATION OF SPECIFIC SURFACE WITH SAMPLE WEIGHT AND POROSITY

CHAPTER III

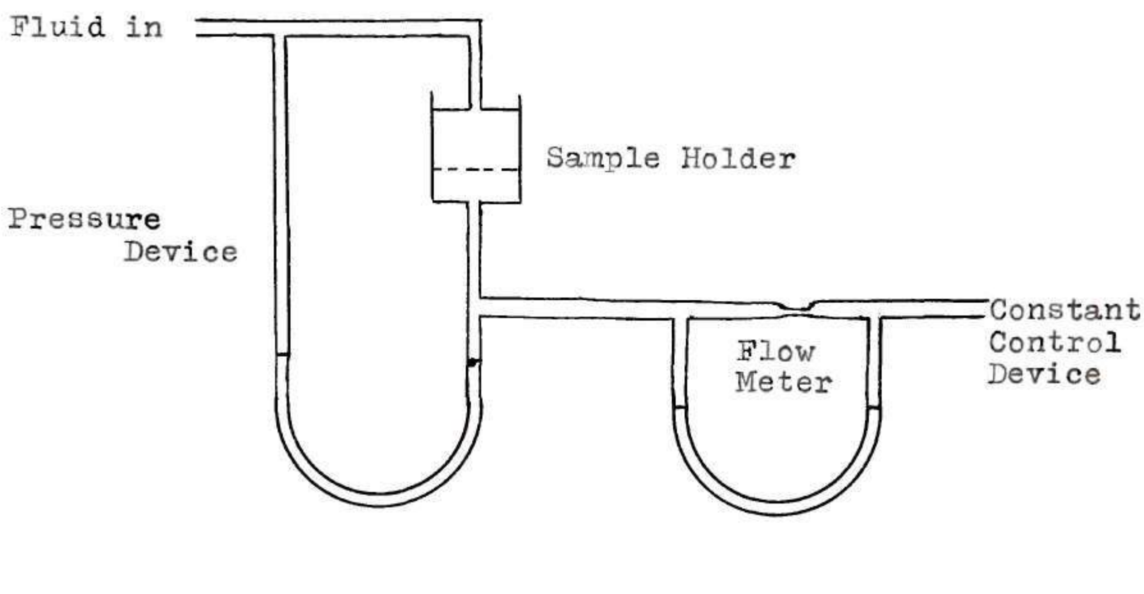
THEORY

I. PRINCIPLE OF THE PERMEAMETER

The permeameter is a device for holding a porous bed of material in such a way that the permeability of the bed can be obtained accurately; the method consists of drawing a measured amount of air or other fluid through the bed and measuring the pressure drop.

FIGURE 2

SCHEMATIC DIAGRAM OF THE PERMEAMETER



(For a more complete explanation of the permeameter used in this investigation, see Figure 5 and explanation in Chapter IV.)

The down and/or feathers are placed in the sample holder and the Carman equation used to calculate the surface area as shown in the investigation.

II. THE CARMAN EQUATION FOR SURFACE MEASUREMENT

A comprehensive discussion of the fundamental principles that underlie the permeameter method are given by Carman[7] along with experimental data to substantiate his theory.[8,9,10] The equation relating surface area and permeability was later modified by Lea and Nurse[11] which became the most widely used. This equation can be obtained from the Kozeny equation expressed in terms of permeability, the constants being in cgs units:[12]

$$S_w = \frac{14}{d} \sqrt{\frac{1}{P'v} \quad \frac{e^3}{(1-e)^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

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[7] P. C. Carman, "Fluid Flow Through Granular Beds" Transactions, Institute of Chemical Engineers, 15:150-66.1937.

[8] P. C. Carman, "The Determination of the Specific Surface of Powders, I," Journal of the Society of Chemical Industry, 57:225-34, July, 1938.

[9] P. C. Carman, "The Determination of the Specific Surface of Powders, Part II," Ibid., 58:1-7, January, 1939.

[10] P. C. Carman, "Shape and Surface of Fine Powders by the Permeability Method", American Society for Testing Materials, Symposium on New Methods for Particle Size Determination in Subsieve Range, March 4, 1941 pp. 24-35.

[11] F. M. Lea and R. W. Nurse, "Specific Surface of Fine Powders", Journal of the Society of Chemical Industry, 58:277-83, September, 1939.

[12] J. M. Dalla Valle, Micromeritics (New York: Pitman Publishing Corporation, 1948) p. 334.

S_w = the specific surface of material, cm.^{2}/gm.
d = density of the material tested, gm./cm.^{3}
e = fraction of void space in sample bed.
P' = the permeability.
v = kinematic viscosity, cm./sec.

The definition of permeability is the pressure drop due to a unit-volume of fluid through a unit-length per unit-time per unit-area and can be written:

$$P' = \frac{q}{A \dfrac{h_1 \; d_1}{L \; d_a}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

P' = the permeability.
q = rate of flow of air or fluid, cm.^{3}/sec.
A = cross-sectional area of bed, cm.^{2}
L = depth of bed, cm.
h_1 = manometer reading measuring pressure across bed in inches of water.
d_1 = density of manometer fluid (water plus corallin) gm./cm^3
d_a = density of air, gm./cm.^{3}

The rate of air flow is related to the manometer reading by the equation:

$$Q = c\, h_2^{\,b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Q = rate of flow of air, liter/hour.
b = slope of plot Q versus h_2.
c = constant of the orifice.
h_2 = flow manometer reading, inches of water.

The combination of these three equations gives the Lea and Nurse modification of the Carman equation:

$$S_w = \frac{14}{d} \sqrt{\frac{e^3}{(1-e)^2} \frac{A\ h_1}{CLh_2{}^b}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

CHAPTER IV

EQUIPMENT AND MATERIAL TESTED

I. EQUIPMENT

Sample Holder. The sample holder used in this investigation is constructed of brass. The body of the sample holder (A)[13] has a six inch over-all length and a three and a half inch outside diameter. The inside is made 2.030 ± 0.001 inches in diameter. The plate (E) fits in from the bottom of the body and is one fourth of an inch thick and two and one quarter inches in diameter containing 81, 3/64 inch holes. This is held in place by part (D) which screws into the bottom of the body. The top of this part has a two inch diameter 45 degree taper that leads into a 1/8 inch hole which has a hose connection.

The piston is six inches in length and is made up of four parts. Part (H) is a one inch section of two inch diameter brass pipe. Part (F) is 3/8 inch thick and is sweated to part (H) and contains 25, 3/64 inch holes. Part (G) has one 1/8 inch hole and is sweated to part (H). The parts (F) and (G) are fitted to the inside diameter of the body as closely as possible in order to obtain a tight

[13]For reference of letters used see Figures 3 and 4 on pages 11 and 13.

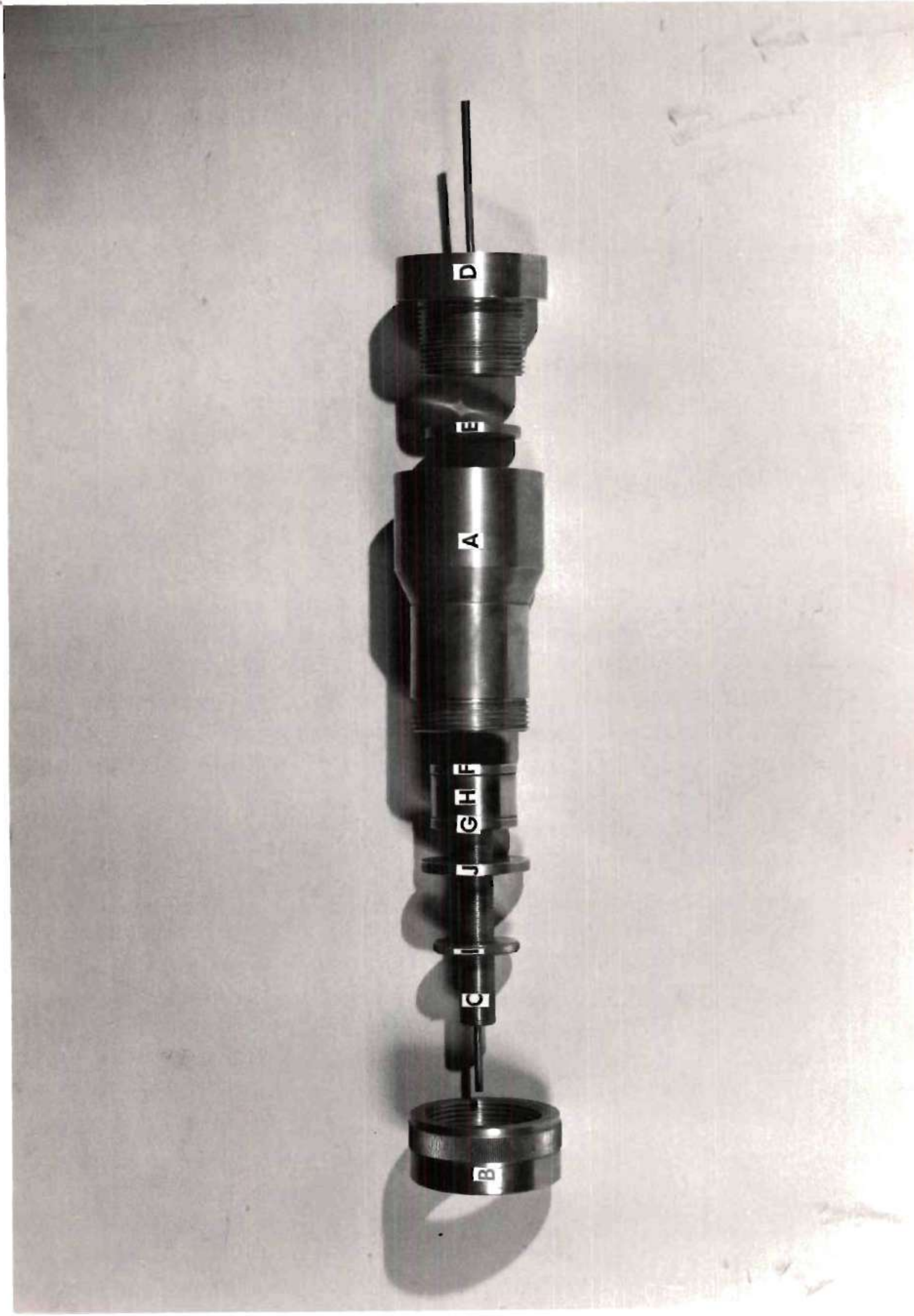

FIGURE 3

COMPONENTS OF THE SAMPLE HOLDER

fit. (about 0.001 inch tolerance) The shaft, part (C), is sweated to part (G) and is 7/8 inch diameter, 20 threads to the inch and 4 1/2 inches in length with a 1/8 inch hole through the center. To the end is sweated a tube connection.

The piston is held at the desired height above the base by part (J) which is 1/4 inch thick, 2 3/4 inches in diameter with 1/16 inch - 1 1/2 inch diameter raised portion. The center is threaded to fit the threads of the piston thus allowing accurate movement. The collar, (B), holds part (J) securely to the top of the body (A). This collar, 3 1/2 inches in diameter, is threaded to fit the body. The top has a 2 1/4 inch diameter hole in the center to allow part (I) to be moved up and down. Part (I) 1/4 inch thick, 2 inches in diameter has the top marked in ten divisions and the side is knurled.

When the parts are assembled, as in Figure 4, the depth of the piston from the bottom can be obtained to an accuracy of 0.0005 inches plus or minus by the estimation of tenths between the marked division of part (I).

<u>Permeameter Set Up</u>. The complete set up can be seen in Figure 5. The sample holder described above is part (1).[14] The other equipment included is part (6) a

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[14]For reference of numbers used see Figure 5 page 14.

FIGURE 4

ASSEMBLED SAMPLE HOLDER

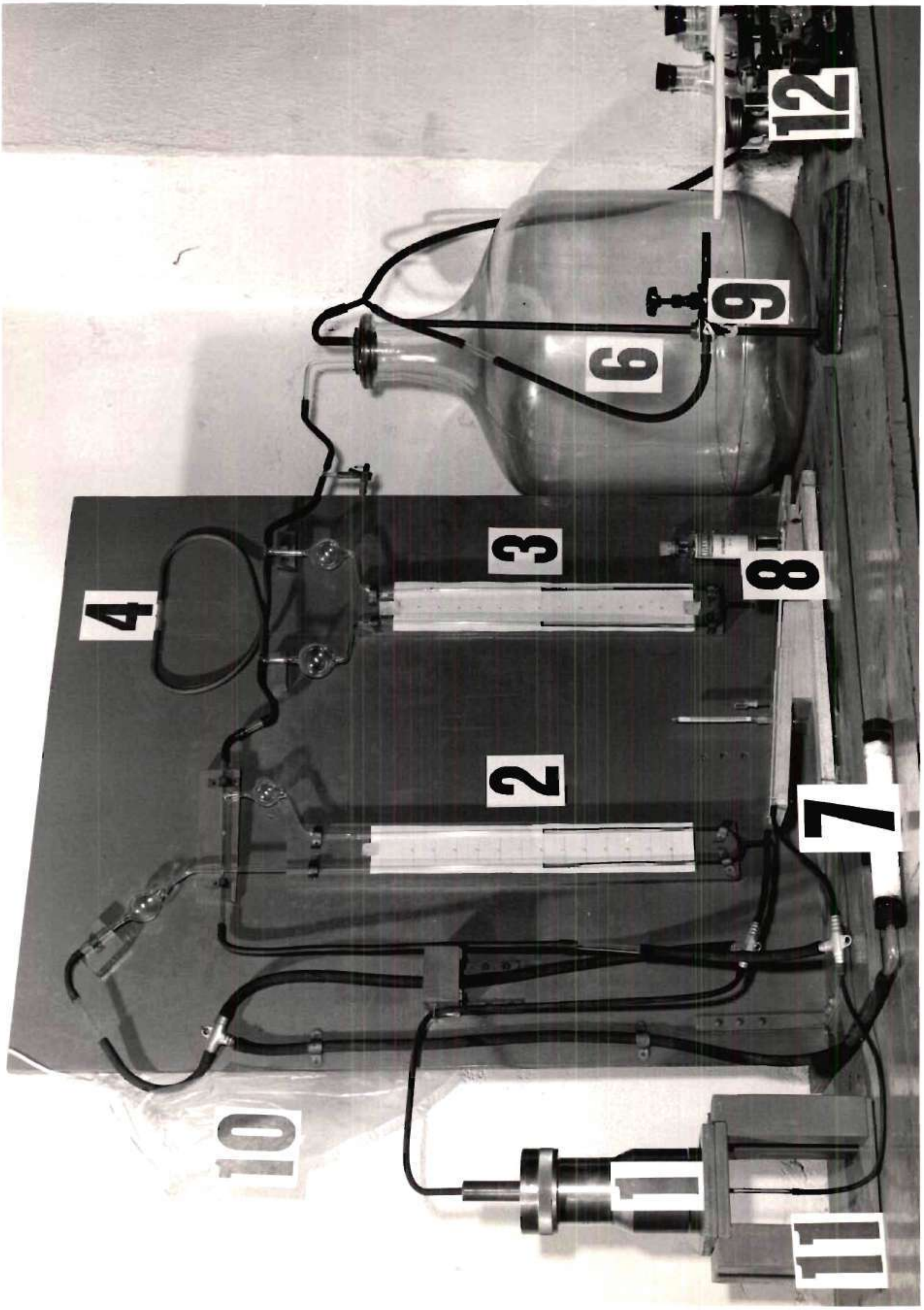

FIGURE 5

COMPLETE PERMEAMETER SET UP

five gallon surge tank to which is connected a vacuum pump. The flow of air can be regulated very closely by a needle valve, part (9), which opens to the atmosphere. With the valve open the minimum air flow through the equipment is obtained. The air enters through a calcium chloride drying tube, part (7), into the sample holder part (1).
The pressure drop manometers are parts (2) and (8). Part (2) is a ten to one inclined plane manometer on which the readings are made. This manometer has a scale length of fifteen inches. Part (3) is the capillary flow manometer with (4) the capillary tube. This equipment is mounted on a perpendicular wooden base. A wooden base (11) holds the sample holder. Part (10) is a tapered cellophane bag with a 1 1/2 inch diameter ring at one end and a wide draw string opening at the other. This bag is used to weigh the sample on scale (12). The forceps are used to transfer the feathers and down mixtures into the body of the sample holder with the piston removed and parts (E) and (D) in place.

II. MATERIAL TESTED

This paper presents the results of experimental investigation on the determination of the percentage of down in down and feather mixtures. Samples of clean and sterilized white Europe goose down and white Europe goose feathers were obtained from National Feather and Down Company, Brooklyn, New York. These samples included the following:

1. White Europe Goose Feathers.

2. White Europe Goose Down.

3. 50% White Europe Goose Down and 50% White Europe Goose Feathers.

4. 25% White Europe Goose Down and 75% White Europe Goose Feathers.

Other samples are made up from the pure white Europe goose down and feather samples obtained. These samples 75% white Europe goose down and 25% white Europe goose feathers, and 10% white Europe goose down and 90% white Europe goose feathers are used as check points against the curve already obtained by experiments with the samples from the National Feather and Down Company, Brooklyn, New York.

CHAPTER V

PROCEDURE

I. PRELIMINARY TESTS

The procedure used in making a run varies with the purpose of the experiment. The first series of tests is run in order to determine the length of time required for the apparatus to obtain equilibrium. In this test all variables are held constant.

The second series of tests is made with only one type of down and feather mixture with the same rates of flow but a variation of the porosity from 0.50 to 0.80. This range was arrived at from the results of Dalla Valle, Clyde Orr, Jr., and R. R. Cornwall's test on fibers.[15]

The third set of tests is made as to the proper weight of sample to use. The same porosity and flow rates are used while the weight of the sample is varied in order to obtain the best degree of reproducibility.

The last set of tests is run holding the weight and porosity constant while the various percentages of down and feathers are changed.

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[15] J. M. Dalla Valle, Clyde Orr, Jr., and R. R. Cornwall, *loc. cit.*

II. DETERMINATION OF MATERIAL DENSITY

An important item of information necessary for the use of the Carman equation (4) is the density of the material tested. A search into the literature gives no results on this type of material. Hence, it was necessary to determine the density by means of the Pycnometer method. The volume of the specific gravity bottle used was determined by the use of distilled water at 30°C. Several samples were tested with various wetting agents. The wetting agent was added to distilled water and the density of the liquid obtained by the same method as the calibration.

Three samples of down and feathers were tested. The results appear below in table I.

TABLE I

DENSITY OF WHITE EUROPE GOOSE DOWN AND FEATHERS

Down	Feathers
1.196	0.8813
1.207	0.8850
1.178	0.8777
Values Used	
1.19	0.88

III. CALIBRATION OF FLOW METER AND CONSTANTS OF PERMEAMETER

The rate of flow for this apparatus set up is based upon the previous studies made. The rate of flow for a one inch diameter cylinder is in the range of six liters of air per hour. The size of this apparatus has been changed such that the diameter has been doubled and thus it is desirable to increase the rate of flow four times that of the one inch diameter cylinder or about 24 liters per hour of air. The range finally settled on is large enough to be increased to one and one-half times that value.

The flow meter is calibrated by a syphon arrangement and the following equation obtained giving the relation between the value of flow and the manometer reading.

$$Q = 5.9\ h_2^{0.79} \qquad (5)$$

where:

Q = flow in liters per hour.
h_2 = inches of water deflection of flow manometer.

The following are the constants of the permeameter assembly used in connection with equation (4) for the calculation of surface area.

A = inside area of the sample holder = 20.9 cm.^{2}
d_1 = density of water and corallin in manometer = 1.00 gm./cm.^{3}
v = kinematic viscosity of air = u/d_a.
d_a = density of air = 1.14×10^{-3} gm./cm.^{3}
u = viscosity of air = 180×10^{-6} gm./cm. sec.

IV. DERIVATION OF EQUATION USED IN CALCULATION OF SURFACE AREA

(1) Rate of Flow:

$$Q = c\, h_2^{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$Q = 5.9\, h_2^{0.79} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

(2) Permeability Definition:

$$P' = \frac{q}{A \dfrac{h_1}{L} \dfrac{d_1}{d_a}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$P' = \frac{\dfrac{5.9\, h_2^{0.79} \times 1000}{60 \times 60}}{20.9 \times \dfrac{h_1 \times 1.00}{L \times 1.14 \times 10^{-3}}}$$

$$P' = 8.95 \times 10^{-5} \times \frac{L\, h_2^{0.79}}{h_1} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

(3) Final Equation:

$$S_w = \frac{14}{d} \sqrt{\frac{1}{P'v} \quad \frac{e^3}{(1-e)^2}} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$$S_w = \frac{14}{d} \sqrt{\frac{10^5 \times 1.14 \times 10^{-3}\, h_1}{8.95\, L\, h_2^{0.79} \times 180 \times 10^{-6}} \frac{e^3}{(1-e)^2}}$$

$$S_w = \frac{3730}{d} \sqrt{\frac{h_1}{L\, h_2^{0.79}} \frac{e^3}{(1-e)^2}} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

Equation (7) can be further simplified since the porosity of the sample used is set at certain fixed values. The following equation results:

$$S_w = \frac{K_e}{d}\sqrt{\frac{h_1}{L\ h_2^{0.79}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

h_1 = corrected pressure manometer reading, inches of water.
h_2 = corrected flow manometer reading, inches of water.
L = depth of bed, cm.
d = density of substance tested, gm./cm.^{3}
K_e = constant.

Thus the porosity function can be calculated and a lumped constant obtained for each of the porosities used. See table II.

TABLE II

CALCULATION OF THE POROSITY FUNCTION

e	0.500	0.600	0.700	0.800
e^3	0.125	0.216	0.343	0.512
$1-e$	0.500	0.400	0.300	0.200
$(1-e)^2$	0.250	0.160	0.090	0.040
$e^3/(1-e)^2$	0.500	1.350	3.811	12.800
$[e^3/(1-e)^2]^{\frac{1}{2}}$	0.707	1.162	1.952	3.578
K_e	2637	4224	7281	13350

V. INHERENT PRESSURE DROP OF PERMEAMETER

The permeameter has a pressure drop inherent in the set up. This value is obtained by using the same piston depth without a bed of feathers and down and is subtracted from the value read on the pressure drop manometer. The inherent pressure drops are given in the following table:

TABLE III

RELATION BETWEEN INHERENT PRESSURE DROP OF SAMPLE HOLDER AND RATE OF FLOW READING

Rate of Flow Reading h_2 (Inches of Water)	Pressure Drop Through Empty Sample Holder (Inches of Water)
1.51	0.020
1.95	0.028
2.02	0.029
3.05	0.045
4.04	0.058
4.94	0.076
6.05	0.089
7.96	0.115
8.97	0.127
9.78	0.143
10.68	0.158

CHAPTER VI

RESULTS

I. EFFECT OF POROSITY

The effect of porosity, as shown by Dalla Valle, Orr, and Cornwall[16], has a critical effect on the surface area determination of fibers. (See Figure I) To obtain the effect of porosity, tests at four different porosities are run 0.80, 0.70, 0.60, and 0.50. The data of tables XII through XV in the appendix are plotted in Figure 6. The sample tested, 50% white Europe goose down and 50% white Europe goose feathers, shows that the calculated value of surface area has a marked and almost regular decrease with decreasing values of porosity. This decrease in calculated surface area is of interest if the actual surface area is desired, however it is not the exact surface area in which we are primarily interested in this investigation. The agreement between the different samples for a given porosity must be taken into consideration since the degree of variation in the values will bear heavily on the final correlation between surface area and percentage of down in a sample.

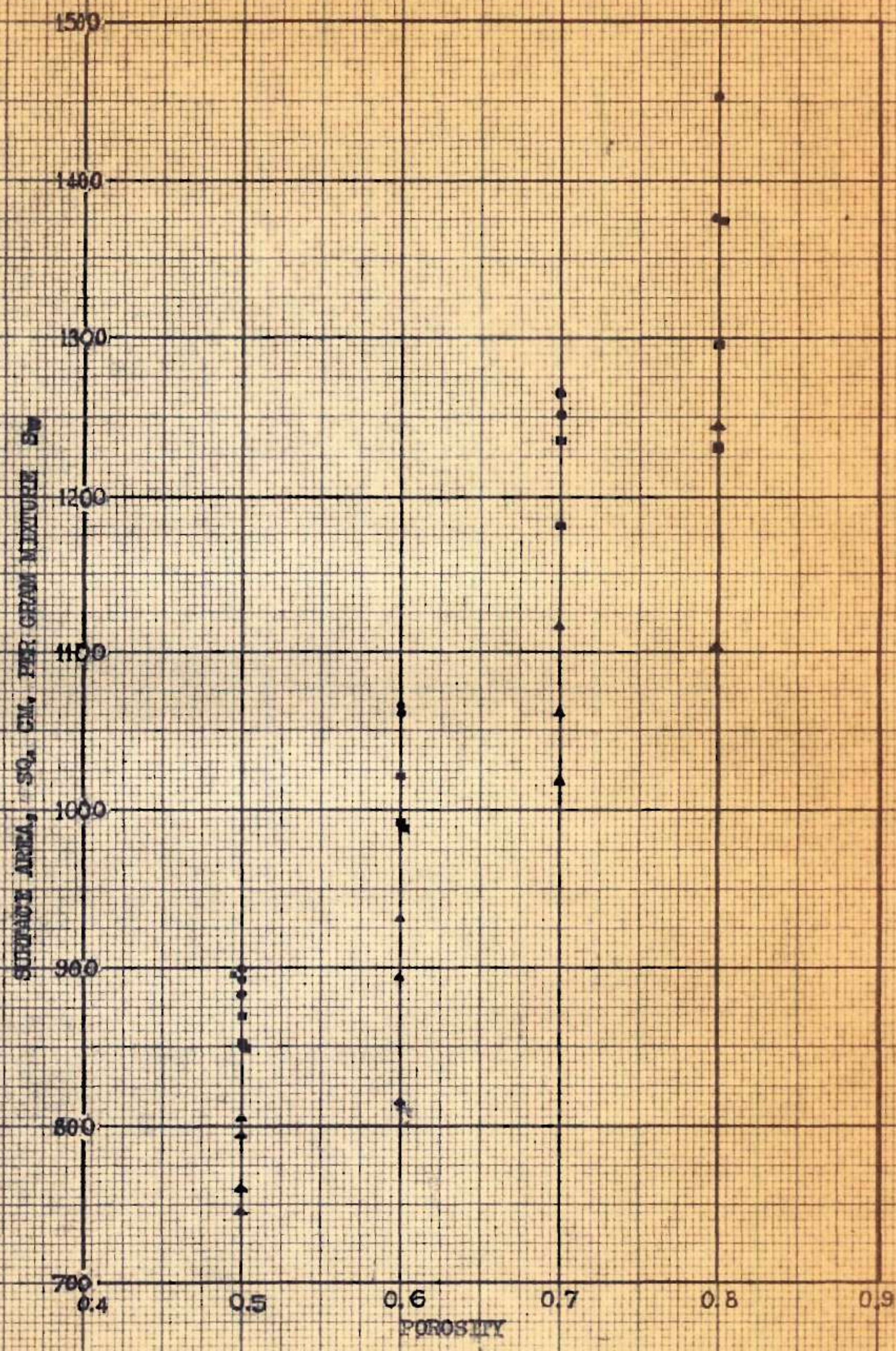
A good degree of agreement between the values at a

[16] J. M. Dalla Valle, Clyde Orr, Jr., and R. R. Cornwall, loc. cit.

FIGURE 6

VARIATION OF SURFACE AREA WITH POROSITY

50% WHITE EUROPE GOOSE FEATHER AND 50% WHITE EUROPE GOOSE DOWN



4.37 gram sample

Flow rates, ● 35 liters, ■ 24 liters, ▲ 10 liters of air / hour porosity of 0.60 is obtained for flow rates of about 35 liters and 24 liters of air per hour. With flow rates as low as 10 liters of air per hour the manometer readings obtained are extremely small and thus subject to comparatively large errors. The other porosities do not show as good agreement as 0.60 porosity. In view of the agreement obtained e = 0.60 is chosen for use throughout the remainder of the investigation.

These results were checked using a different sample weight, using an e = 0.70, indicating that the value of e = 0.60 produces better agreement at a given rate of flow. (See table X and XI in the appendix.)

II. EFFECT OF SAMPLE WEIGHT

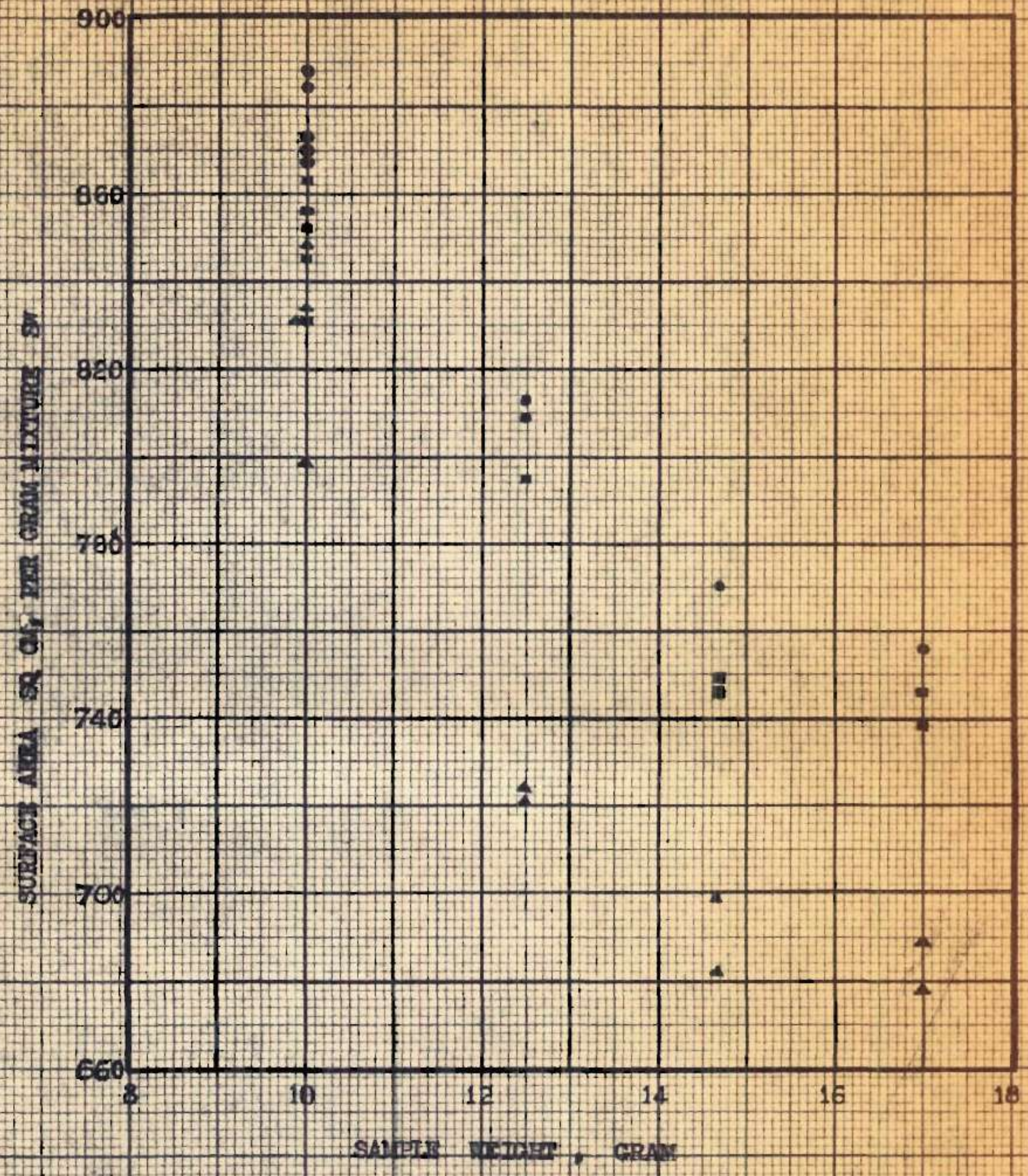
Another important variable is the sample weight. The data of tables III through VII in the appendix are plotted in Figure 7. White Europe goose down is used in this investigation and the weight of the sample is varied from 10.00 grams to 17.00 grams, the total weight of the white Europe goose down available.

The trend of the data indicates that with a sample weight of about ten grams, the effect of weight on the surface area is negligible. At 0.60 porosity this weight forms a bed of about three centimeters in depth. The degree of variation between the points on several samples

FIGURE 7

VARIATION OF SURFACE AREA WITH SAMPLE WEIGHT

WHITE EUROPE GOOSE DOWN



0.6 porosity

● Flow rate 33 liters air per hour
■ Flow rate 24 liters air per hour
▲ Flow rate 10 liters air per hour

is small for all weights tested.

III. EFFECT OF FLOW RATES

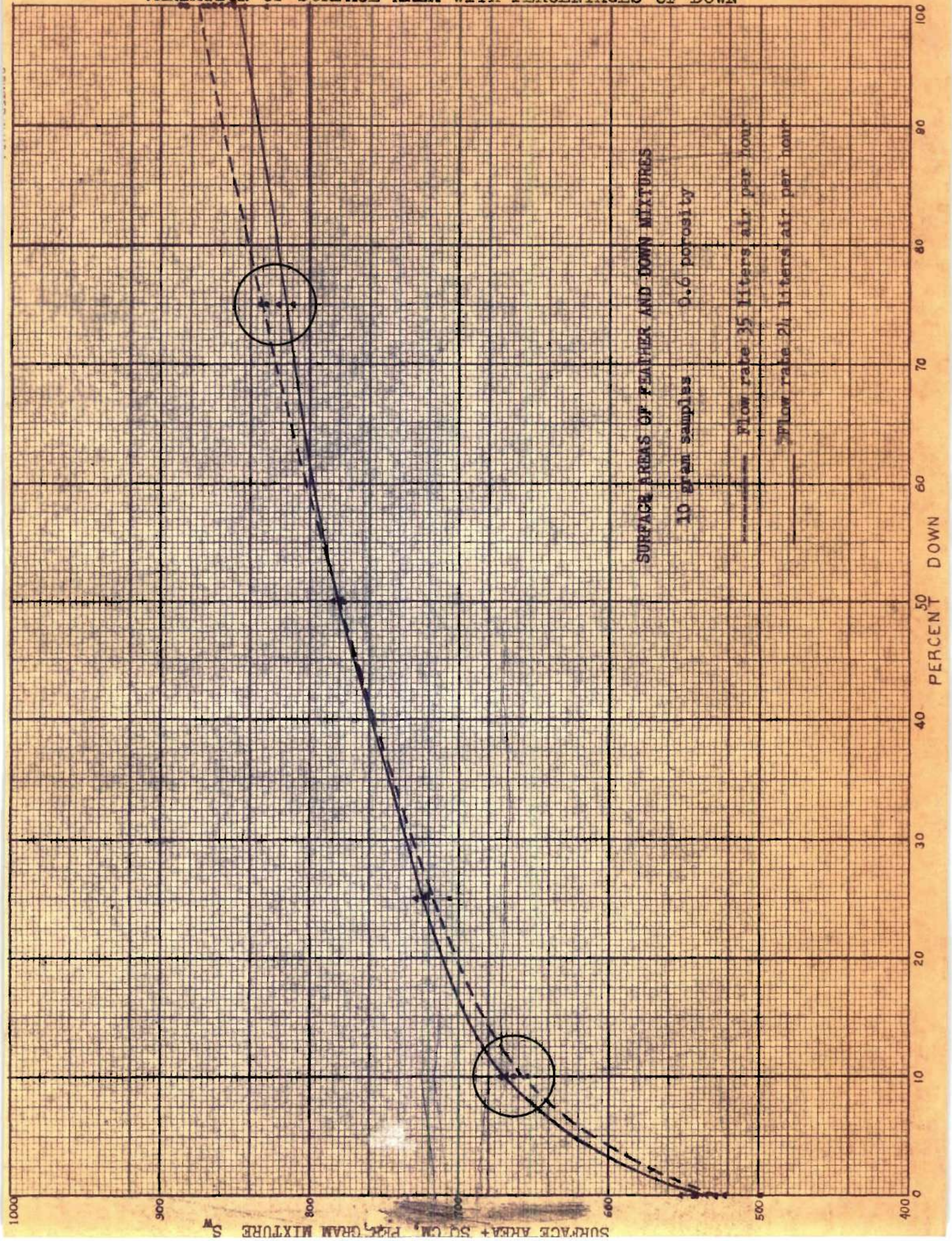
The effect of flow rates of air is obtained from tables III through V, IX, X, XVI through XIX, summarized in table I of the appendix, and is plotted in Figure 8. The effect of flow rate is very small except at high percentages of down. Since the object of this investigation is to correlate the surface area of the sample to the percentage of down in a sample, the variation caused by flow rates is of importance.

The lowest flow rate of ten liters of air per hour does not prove satisfactory since the pressure drop readings taken on the inclined plane are small. Any errors in reading would result in a marked degree of inaccuracy. For this reason flow rates of 24 and 36 liters of air per hour are selected which give uniform results. The results as mentioned above are indicated in the tables referred to in the appendix and in Figure 8.

IV. REPRODUCIBILITY

The reproducibility of results was checked at both ends of the curve shown in Figure 8. The check on white Europe goose feathers can be found in tables XVIII and XIX of the appendix. The agreement between the results

VARIATION OF SURFACE AREA WITH PERCENTAGES OF DOWN



and the average of the results is about a 3% error. Another check is run on white Europe goose down and can be found in tables III, IV, and V of the appendix. The agreement between the individual results and the average of the individual results is about a 2% error. These two conclusions indicate good reproducibility.

The curve shown in Figure 8 is first made from the average of the surface area values for four different percentages of down. Pure white Europe goose feathers, white Europe goose down, 25% white Europe goose down and 75% white Europe goose feathers, and 50% white Europe goose down and 50% white Europe goose feathers, samples obtained from National Feather and Down Company. Two other samples consisted of 10% white Europe goose down and 90% white Europe goose feathers, and 75% white Europe goose down and 25% white Europe goose feathers. These last two samples are run to check the reproducibility of the curve.

Taking the most divergent of the four check results (24 liters of air flow at 75% white Europe goose down and 25% white Europe goose feathers) the highest value is about 4% high and the lowest about 3% low in percentage of down indicated. This reproducibility of results gives closer agreement to the sample percentage than those allowed by the New York State Bedding Law.

CHAPTER VII

I. CONCLUSIONS

The results of this investigation can be seen in Figure 8 which gives the correlation between surface area of a sample and the percentages of down present. This graph is, of course, for one type of down and feather mixtures. The study of the effect of porosity, sample weight and flow rate, indicates that a 10.00 gram sample run at 0.60 porosity with a flow of 24 and 35 liters per hour will give two values that are in good agreement as to the percentage of down present. The degree of reproducibility of the results is better than the values allowed by the New York State Bedding Law and the time required for analysis is considerably less than the present method.

II. RECOMMENDATIONS

Based on this investigation the following recommendations are proposed:

(1) The sample holder described in the text should be used because it gives a random distribution of the down and feathers.

(2) A weight sample of ten (10.00) grams should be used.

(3) The porosity should be fixed at 0.60.

(4) The flow rate should be 35 liters of air per hour to give the best reproducibility.

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APPENDIX

The symbols used in the following tables are derived from equation (8):

$$S_w = \frac{K_e}{d}\sqrt{\frac{h_1}{L\,h_2^{0.79}}}$$

S_w = Surface area, cm.^{2}/gm.
K_e = Constant for a particular porosity. (See table II in text)
d = Density of sample being tested, gm./cm.^{3}
h_1 = Corrected pressure drop reading, inches of water.
L = Height of bed, cm.
$h_2^{0.79}$ = Corrected flow manometer reading.
h'_1 = Pressure drop reading before correction. (See table III in text for inherent pressure drop)
h_2 = Flow manometer reading before corrected.
r = $h_1/h_2^{0.79}$ = a ratio.
e = Porosity or fractional voids.
Q = Rate of flow, liters of air per hour.

APPENDIX

TABLE I: White Europe Goose Feathers and White Europe Goose Down, Percentages of Down and Surface Area

$e = 0.60$
10.00 gram sample

Percentage of Down Present

100	75	50	25	10	0
----------Flow rate about 35 liters per hour----------------					
888	830	779	724	663	499
884	833	777	706	654	542
870	---	---	---	---	542
865	---	---	---	---	---
873	---	---	---	---	---
----------Flow rate about 24 liters per hour----------------					
863	811	783	724	677	523
852	822	779	728	672	552
845	---	---	---	---	533
831	---	---	---	---	528
852	---	---	---	---	---
856	---	---	---	---	---

APPENDIX

TABLE II: Time Check on Equilibrium on White Europe Goose Down.

$\epsilon = 0.60$

10.00 gram sample

$d = 1.19$ $K_e = 4224$ $L = 3.041$ cm. $K_e/d = 3550$

Time

	1.0 min.	2.0 min.	15.0 min.	2.0 min.	15.0 min.
h'_1	1.221	1.253	1.246	1.226	1.232
h_1	1.076	1.109	1.103	1.086	1.089
h_2	9.91	9.79	9.73	9.55	9.72
$h_2^{0.79}$	6.13	6.09	6.05	6.00	6.04
r	0.1755	0.1821	0.1823	0.1810	0.1803
r/L	0.05772	0.05988	0.05995	0.05952	0.05929
$(r/L)^{\frac{1}{2}}$	0.2402	0.2447	0.2448	0.2439	0.2435
S_w	852.7	868.7	869.0	865.8	864.4

APPENDIX

TABLE III: White Europe Goose Down.

$e = 0.60$

10.00 gram sample
$d = 1.19$ $K_e = 4224$ $L = 3.041$ cm. $K_e/d = 3550$

Q	10.2	23.9	35.9	9.7	24.3	35.3
h'_1	0.277	0.786	1.270	0.268	0.817	1.240
h_1	0.248	0.700	1.124	0.242	0.729	1.097
h_2	2.01	5.95	9.97	1.90	6.06	9.76
$h_2^{0.79}$	1.74	4.00	6.15	1.65	4.12	6.13
r	o.1431	0.1750	0.1828	0.1467	0.1769	0.1807
r/L	0.0471	0.0576	0.0601	0.0482	0.0582	0.0594
$(r/L)^{\frac{1}{2}}$	0.217	0.240	0.245	0.220	0.241	0.244
S_w	770	852	870	781	856	867

APPENDIX

TABLE IV: White Europe Goose Down

$e = 0.60$

10.00 gram sample
$d = 1.19$ $K_e = 4224$ $L = 3.041$cm. $K_e/d = 3550$

Q	35.1	23.1	9.6	9.6	23.6	35.8
h'_1	1.256	0.773	0.301	0.278	0.762	1.269
h_1	1.113	0.689	0.275	0.253	0.677	1.123
h_2	9.72	5.72	1.86	1.85	5.87	9.94
$h_2^{0.79}$	6.05	4.00	1.64	1.64	4.08	6.15
r	0.1840	0.1723	0.1677	0.1543	0.1659	0.1826
r/L	0.0605	0.0566	0.0551	0.0507	0.0546	0.0601
$(r/L)^{\frac{1}{2}}$	0.246	0.238	0.235	0.225	0.234	0.245
S_w	873	845	834	799	831	870

APPENDIX

TABLE V: White Europe Goose Down.

$e = 0.60$

10.00 gram sample
$d = 1.19$ $K_e = 4224$ $L = 3.041$ cm. $K_e/d = 3550$

Q	35.3	23.4	10.2	10.2	23.7	35.5
h'_1	1.295	0.811	0.327	0.317	0.800	1.303
h_1	1.151	0.726	0.300	0.289	0.715	1.158
h_2	9.78	5.83	2.00	2.01	5.90	9.85
$h_2^{0.79}$	6.08	4.03	1.73	1.74	4.09	6.11
r	0.1893	0.1801	0.1744	0.1661	0.1748	0.1895
r/L	0.0623	0.0592	0.0574	0.0546	0.0575	0.0623
$(r/L)^{\frac{1}{2}}$	0.249	0.243	0.239	0.234	0.240	0.250
S_w	884	863	848	831	852	888

APPENDIX

TABLE VI: White Europe Goose Down.

$e = 0.60$

12.48 gram sample
$d = 1.19$ $K_e = 4224$ $L = 3.795$ cm. $K_e/d = 3550$

Q	10.3	24.2	35.8	10.2	24.3	35.8
h'_1	0.311	0.870	1.353	0.312	0.877	1.358
h_1	0.275	0.782	1.208	0.276	0.789	1.218
h_2	2.04	6.04	9.92	2.00	6.05	9.92
$h_2^{0.79}$	1.75	4.12	6.13	1.73	4.13	6.13
r	0.1571	0.1898	0.1971	0.1595	0.1910	0.1987
r/L	0.0414	0.0500	0.0519	0.0418	0.0503	0.0524
$(r/L)^{\frac{1}{2}}$	0.203	0.224	0.228	0.204	0.224	0.229
S_w	721	795	809	724	795	813

APPENDIX

TABLE VII: White Europe Goose Down.

$e = 0.60$

14.69 gram sample

$d = 1.19$ $K_e = 4224$ $L = 4.467$ cm. $K_e/d = 3550$

Q	10.2	24.3	36.0	10.3	24.3	35.8
h'_1	0.318	0.899	1.444	0.337	0.908	1.440
h_1	0.287	0.811	1.298	0.305	0.820	1.294
h_2	2.02	6.05	9.99	2.05	6.06	9.95
$h_2^{0.79}$	1.74	4.12	6.16	1.76	4.13	6.14
r	0.1649	0.1969	0.2107	0.1733	0.1986	0.2108
r/L	0.0369	0.0441	0.0472	0.0388	0.0445	0.0472
$(r/L)^{\frac{1}{2}}$	0.192	0.210	0.217	0.197	0.211	0.217
S_w	682	746	770	699	749	770

APPENDIX

TABLE VIII: White Europe Goose Down.

$e = 0.60$

17.00 gram sample
$d = 1.19$ $K_e = 4224$ $L = 5.170$ cm. $K_e/d = 3550$

Q	10.5	24.3	33.2	24.3	33.3	9.5
h'_1	0.374	1.009	1.463	1.026	1.472	0.341
h_1	0.336	0.921	1.331	0.938	1.338	0.316
h_2	2.08	6.05	9.04	6.05	9.09	1.84
$h_2^{0.79}$	1.78	4.13	5.70	4.13	5.71	1.63
r	0.1888	0.2230	0.2335	0.2271	0.2343	0.1939
r/L	0.0365	0.0431	0.0452	0.0439	0.0453	0.0375
$(r/L)^{\frac{1}{2}}$	0.191	0.208	0.213	0.210	0.213	0.194
S_w	678	738	756	746	756	689

APPENDIX

TABLE IX: 25% White Europe Goose Feathers and 75% White Europe Goose Down.

$e = 0.60$

10.00 gram sample
$d = 1.11$ $K_e = 4224$ $L = 3.041$ cm. $K_e/d = 3805$

Q	23.1	36.0	10.2	23.9	35.1
h'_1	0.628	1.043	0.254	0.666	1.021
h_1	0.546	0.894	0.226	0.580	0.878
h_2	5.70	10.00	2.01	5.98	9.72
$h_2^{0.79}$	3.95	6.17	1.74	4.10	6.03
r	0.1382	0.1447	0.1299	0.1415	0.1463
r/L	0.0455	0.0476	0.0427	0.0465	0.0481
$(r/L)^{\frac{1}{2}}$	0.213	0.218	0.207	0.216	0.219
S_w	811	830	788	822	833

APPENDIX

TABLE X: 50% White Europe Goose Feathers and 50% White Europe Goose Down.

$e = 0.60$

10.00 gram sample
$d = 1.03$ $K_e = 4224$ $L = 3.041$ cm. $K_e/d = 4101$

Q	10.2	23.9	35.4	23.7	10.2	35.4
h'_1	0.238	0.540	0.814	0.536	0.242	0.832
h_1	0.210	0.454	0.669	0.451	0.214	0.687
h_2	2.02	5.95	9.82	5.88	2.00	9.82
$h_2^{0.79}$	1.74	4.11	6.10	4.09	1.73	6.10
r	0.1207	0.1105	0.1097	0.1103	0.1237	0.1126
r/L	0.0397	0.0363	0.0361	0.0363	0.0407	0.0370
$(r/L)^{\frac{1}{2}}$	0.199	0.191	0.190	0.190	0.202	0.192
S_w	816	783	779	779	824	787

APPENDIX

TABLE XI: 50% White Europe Goose Feathers and 50% White Europe Goose Down.

$e = 0.70$

10.00 gram sample
$d = 1.03$ $K_e = 7281$ $L = 4.054$ cm. $K_e/d = 7069$

Q	35.0	23.7	10.2	23.4	34.9
h_1'	0.492	0.382	0.216	0.317	0.504
h_1	0.347	0.292	0.181	0.227	0.364
h_2	9.68	5.88	2.00	5.78	9.64
$h_2^{0.79}$	6.00	4.09	1.73	4.01	6.00
r	0.0578	0.0717	0.1046	0.0566	0.0607
r/L	0.0143	0.0177	0.0258	0.0140	0.0150
$(r/L)^{\frac{1}{2}}$	0.120	0.133	0.126	0.118	0.122
S_w	848	940	891	834	862

APPENDIX

TABLE XII: 50% White Europe Goose Feathers and 50% White Europe Goose Down.

$e = 0.50$

4.37 gram sample
$d = 1.03$ $K_e = 2637$ $L = 1.063$ cm. $K_e/d = 2560$

Q	9.6	24.2	35.5	9.6	23.5	35.4
h'_1	0.194	0.585	0.914	0.201	0.584	0.940
h_1	0.163	0.494	0.774	0.169	0.495	0.801
h_2	1.86	6.04	9.84	1.85	5.85	9.80
$h_2^{0.79}$	1.59	4.16	6.11	1.63	4.05	6.08
r	0.1025	0.1188	0.1267	0.1037	0.1222	0.1315
r/L	0.0964	0.1118	0.1192	0.0986	0.1150	0.1237
$(r/L)^{\frac{1}{2}}$	0.310	0.333	0.345	0.314	0.339	0.351
S_w	794	852	883	804	868	899

Q	10.2	23.8	35.7	9.8	24.2	35.4
h'_1	0.189	0.581	0.939	0.191	0.578	0.943
h_1	0.155	0.492	0.799	0.158	0.487	0.804
h_2	1.99	5.93	9.89	1.94	6.03	9.82
$h_2^{0.79}$	1.72	4.10	6.13	1.69	4.14	6.13
r	0.0901	0.1200	0.1303	0.0935	0.1176	0.1312
r/L	0.0848	0.1129	0.1226	0.0880	0.1106	0.1234
$(r/L)^{\frac{1}{2}}$	0.291	0.350	0.349	0.297	0.332	0.351
S_w	745	896	893	760	850	899

APPENDIX

TABLE XIII: 50% White Europe Goose Feathers and 50% White Europe Goose Down

$e = 0.60$

4.37 gram sample
$d = 1.03$ $K_e = 4224$ $L = 1.329$ cm. $K_e/d = 4101$

Q	9.9	23.9	35.7	9.7	23.5
h'_1	0.148	0.409	0.679	0.153	0.427
h_1	0.107	0.316	0.544	0.113	0.334
h_2	1.95	5.95	9.88	1.89	5.84
$h_2^{0.79}$	1.70	4.11	6.12	1.65	4.04
r	0.0629	0.0769	0.0889	0.0685	0.0827
r/L	0.0474	0.0579	0.0669	0.0515	0.0622
$(r/L)^{\frac{1}{2}}$	0.218	0.241	0.259	0.227	0.249
S_w	894	988	1062	931	1021

Q	35.5	10.0	23.7	35.7
h'_1	0.686	0.131	0.412	0.683
h_1	0.551	0.090	0.319	0.547
h_2	9.83	1.98	5.92	9.91
$h_2^{0.79}$	6.12	1.72	4.10	6.13
r	0.0900	0.0523	0.0778	0.0892
r/L	0.0677	0.0394	0.0585	0.0671
$(r/L)^{\frac{1}{2}}$	0.260	0.198	0.242	0.259
S_w	1066	812	992	1062

APPENDIX

TABLE XIV: 50% White Europe Goose Feathers and 50% White Europe Goose Down.

$e = 0.70$

4.37 gram sample
$d = 1.03$ $K_e = 7281$ $L = 1.772$ cm. $K_e/d = 7069$

Q	9.7	24.0	35.4	9.7	23.8
h'_1	0.098	0.292	0.482	0.105	0.311
h_1	0.066	0.204	0.344	0.073	0.224
h_2	1.88	6.00	9.82	1.90	5.96
$h_2^{0.79}$	1.65	4.12	6.08	1.66	4.11
r	0.0400	0.0495	0.0566	0.0440	0.0545
r/L	0.0226	0.0279	0.0319	0.0248	0.0308
$(r/L)^{\frac{1}{2}}$	0.150	0.167	0.179	0.158	0.175
S_w	1060	1181	1265	1117	1237

Q	36.0	10.3	23.9	35.2
h'_1	0.497	0.098	0.290	0.469
h_1	0.352	0.064	0.203	0.336
h_2	10.00	2.03	5.95	9.74
$h_2^{0.79}$	6.17	1.73	4.17	6.04
r	0.0571	0.0370	0.0494	0.0556
r/L	0.0322	0.0209	0.0279	0.0314
$(r/L)^{\frac{1}{2}}$	0.179	0.144	0.167	0.177
S_w	1265	1018	1181	1251

APPENDIX

TABLE XV: 50% White Europe Goose Feathers and 50% White Europe Goose Down.

$e = 0.80$

4.37 gram sample
$d = 1.03$ $K_e = 13350$ $L = 2.658$ cm. $K_e/d = 12960$

Q	9.9	23.7	35.4	9.7
h'_1	0.075	0.206	0.334	0.082
h_1	0.033	0.110	0.204	0.041
h_2	1.95	5.90	9.82	1.91
$h_2^{0.79}$	1.69	4.09	6.09	1.66
r	0.0194	0.0268	0.0334	0.0247
r/L	0.0073	0.0101	0.0126	0.0093
$(r/L)^{\frac{1}{2}}$	0.085	0.100	0.112	0.096
S_w	1102	1296	1452	1244

Q	23.5	35.9	23.7	35.8
h'_1	0.216	0.348	0.195	0.323
h_1	0.121	0.206	0.099	0.183
h_2	5.85	9.98	5.91	9.92
$h_2^{0.79}$	4.05	6.15	4.09	6.13
r	0.0299	0.0335	0.0242	0.0299
r/L	0.0112	0.0126	0.0091	0.0112
$(r/L)^{\frac{1}{2}}$	0.106	0.112	0.095	0.106
S_w	1374	1452	1231	1374

APPENDIX

TABLE XVI: 75% White Europe Goose Feathers and 25% White Europe Goose Down.

$e = 0.60$

10.00 gram sample

$d = 0.958$ $K_e = 4224$ $L = 3.041$ cm. $K_e/d = 4412$

Q	35.4	23.4	10.0	35.7	23.4	10.2
h'_1	0.624	0.412	0.192	0.643	0.414	0.194
h_1	0.479	0.328	0.164	0.498	0.331	0.166
h_2	9.82	5.83	1.98	9.88	5.78	2.02
$h_2^{0.79}$	6.10	4.03	1.72	6.09	4.02	1.74
r	0.0785	0.0814	0.0954	0.0818	0.0823	0.0954
r/L	0.0258	0.0268	0.0314	0.0269	0.0271	0.0314
$(r/L)^{\frac{1}{2}}$	0.160	0.164	0.177	0.164	0.165	0.177
S_w	706	724	781	724	728	781

APPENDIX

TABLE XVII: 90% White Europe Goose Feathers and 10% White Europe Goose Down.

$e = 0.60$

10.00 gram sample

$d = 0.91$ $K_e = 4224$ $L = 3.041$ cm. $K_e/d = 4637$

Q	10.3	22.1	36.0	10.2	23.9	35.7
h'_1	0.117	0.300	0.531	0.113	0.319	0.516
h_1	0.089	0.246	0.385	0.085	0.261	0.370
h_2	2.03	5.41	9.99	2.02	5.95	9.90
$h_2^{0.79}$	1.75	3.81	6.16	1.74	4.09	6.12
r	0.0509	0.0646	0.0625	0.0489	0.0638	0.0606
r/L	0.0167	0.0212	0.0206	0.0161	0.0210	0.0199
$(r/L)^{\frac{1}{2}}$	0.129	0.146	0.143	0.127	0.145	0.141
S_w	598	677	663	589	672	654

APPENDIX

TABLE XVIII: White Europe Goose Feathers

$e = 0.60$

10.00 gram sample
$d = 0.88$ $K_e = 4224$ $L = 3.041$ cm. $K_e/d = 4800$

Q	9.8	24.7	35.7	10.8	23.9	35.8
h'_1	0.086	0.246	0.387	0.095	0.238	0.387
h_1	0.059	0.157	0.240	0.065	0.152	0.240
h_2	1.94	6.15	9.93	2.15	5.97	9.94
$h_2^{0.79}$	1.70	4.20	6.14	1.84	4.10	6.14
r	0.0347	0.0374	0.0391	0.0353	0.0371	0.0391
r/L	0.0114	0.0123	0.0129	0.0116	0.0122	0.0129
$(r/L)^{\frac{1}{2}}$	0.107	0.111	0.113	0.108	0.110	0.113
S_w	514	533	542	518	528	542

APPENDIX

TABLE XIX: White Europe Goose Feathers

$e = 0.60$

10.00 gram sample
$d = 0.88$ $K_e = 4224$ $L = 3.041$ cm. $K_e/d = 4800$

Q	10.3	23.6	35.7	23.5	10.2
h'_1	0.136	0.232	0.343	0.246	0.146
h_1	0.108	0.147	0.200	0.162	0.119
h_2	2.05	5.87	9.89	5.85	2.00
$h_2^{0.79}$	1.77	4.08	6.14	4.05	1.73
r	0.0610	0.0360	0.0326	0.0400	0.0688
r/L	0.0201	0.0119	0.0107	0.0132	0.0226
$(r/L)^{\frac{1}{2}}$	0.141	0.109	0.104	0.115	0.150
S_W	677	523	499	552	720